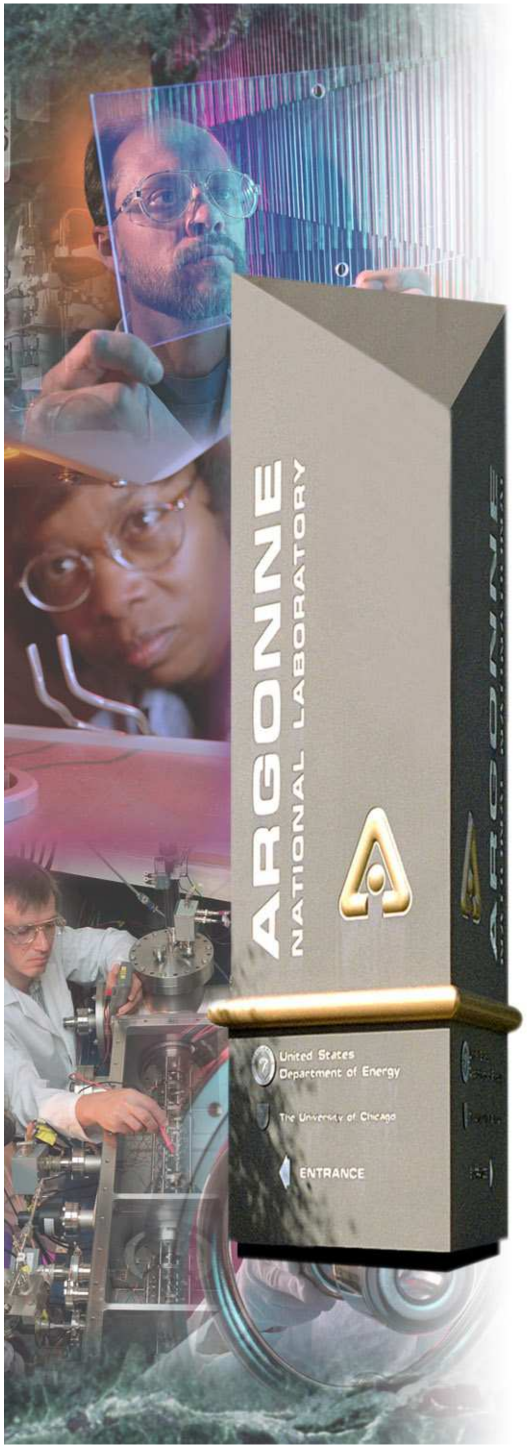

Injector Requirements for APS Operations

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Outline

- APS injector top-up requirements.
- Present APS injector configuration and operation.
- Injector operating envelope considerations.
- Direct injection.
  - Bunch purity data taken for direct injection using rf gun 2.
  - Simulation of linac macropulse capture using a subharmonic booster rf cavity.
  - Long drive pulse laser assisted rf thermionic guns.
- Interleaving for simultaneous LEUTL and top-up operation.
- Conclusion.

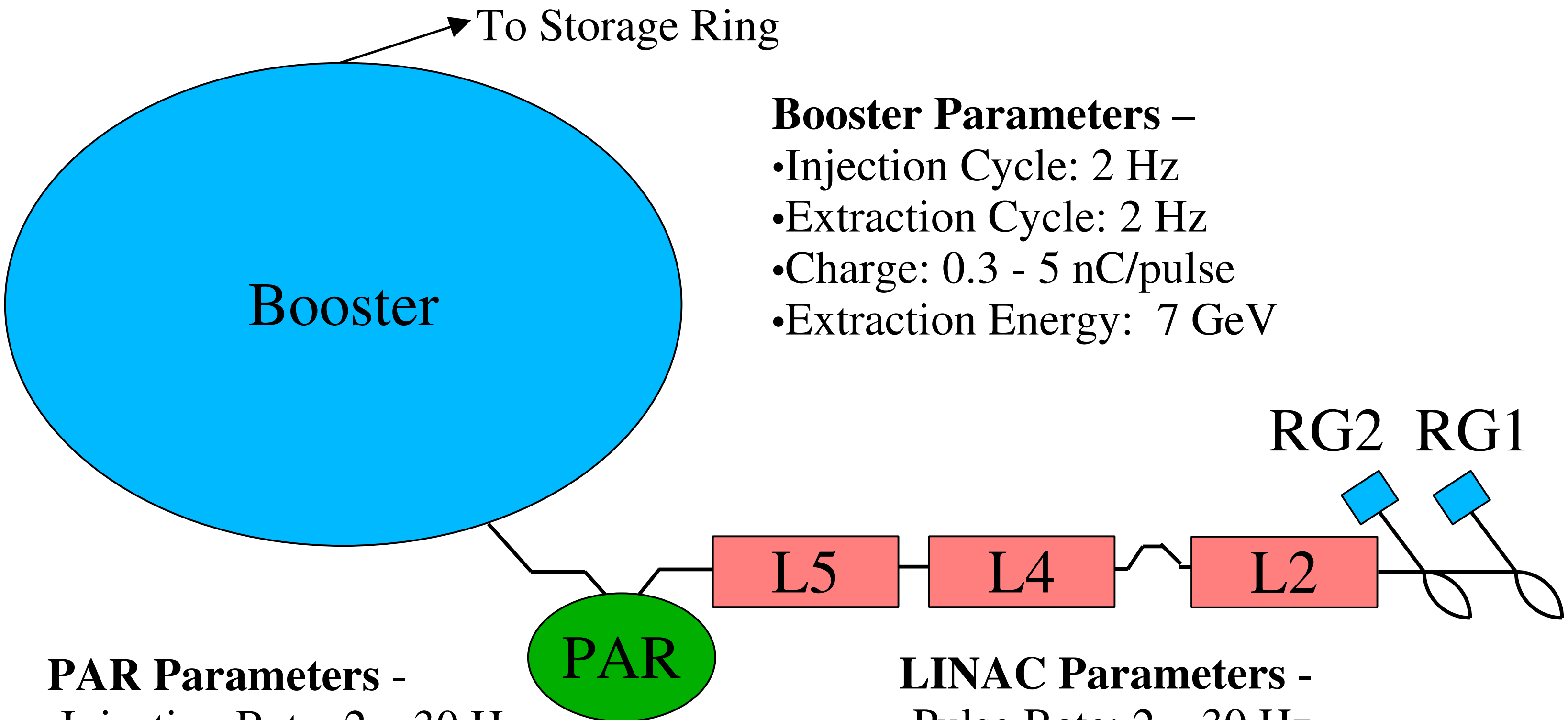
APS Injector Top-up Requirements

- Top-up allows running the SR with low effective emittance and therefore lifetime (~6 hours).
- Single-pulse injection occurs every 2 minutes.
- Injector charge / pulse depends on lifetime and injection efficiency (~80-90 %).
- This mode is the most demanding on the injectors.
- Typically top-up requires 2 - 3.5 nC/cycle to support top-up.
- The single injected pulse must land in one of 23 single buckets (singlets) with good bunch purity for timing experiments.

Standard Storage Ring Operation Modes

- **23 singlets (24 soon) each separated by 150 ns.**
  - Primary operating mode.
  - Lifetime ~ 6 hours, requires top-up for low-emittance lattice.
  - Booster provides 7 GeV and 2.0-3.5 nC/cycle depending on lifetime and injection efficiency.
  - Bunch purity requires the particle accumulator ring (PAR).
- **324 bunch operation.**
  - Allows injector studies during storage ring operations.
  - Long lifetime of ~ 60-70 hours so top-up not required even with low-emittance top-up lattice.
  - Fill every 12 hours.
  - 0.3 to 0.5 nC/cycle for each fill-on-fill.

Injector Configuration and Operation for Storage Ring Operations



Booster Parameters –
- Injection Cycle: 2 Hz
- Extraction Cycle: 2 Hz
- Charge: 0.3 - 5 nC/pulse
- Extraction Energy: 7 GeV

PAR Parameters -
- Injection Rate: 2 – 30 Hz
- Extraction Cycle: 2 Hz
- Injection Pulses: 1-5
- Extracted Charge: 0.3 – 5 nC
- Injection Energy: 325 MeV
- Fundamental rf : h = 1
- Harmonic rf: h = 12

LINAC Parameters -
- Pulse Rate: 2 – 30 Hz
- Injection Pulses: 1-5
- Extracted Charge: 0.3 – 1 nC
- Extraction Energy: 325 MeV
- RG2 Macropulse Length – 11-16 ns
- RG1 Macropulse Length – 30 ns

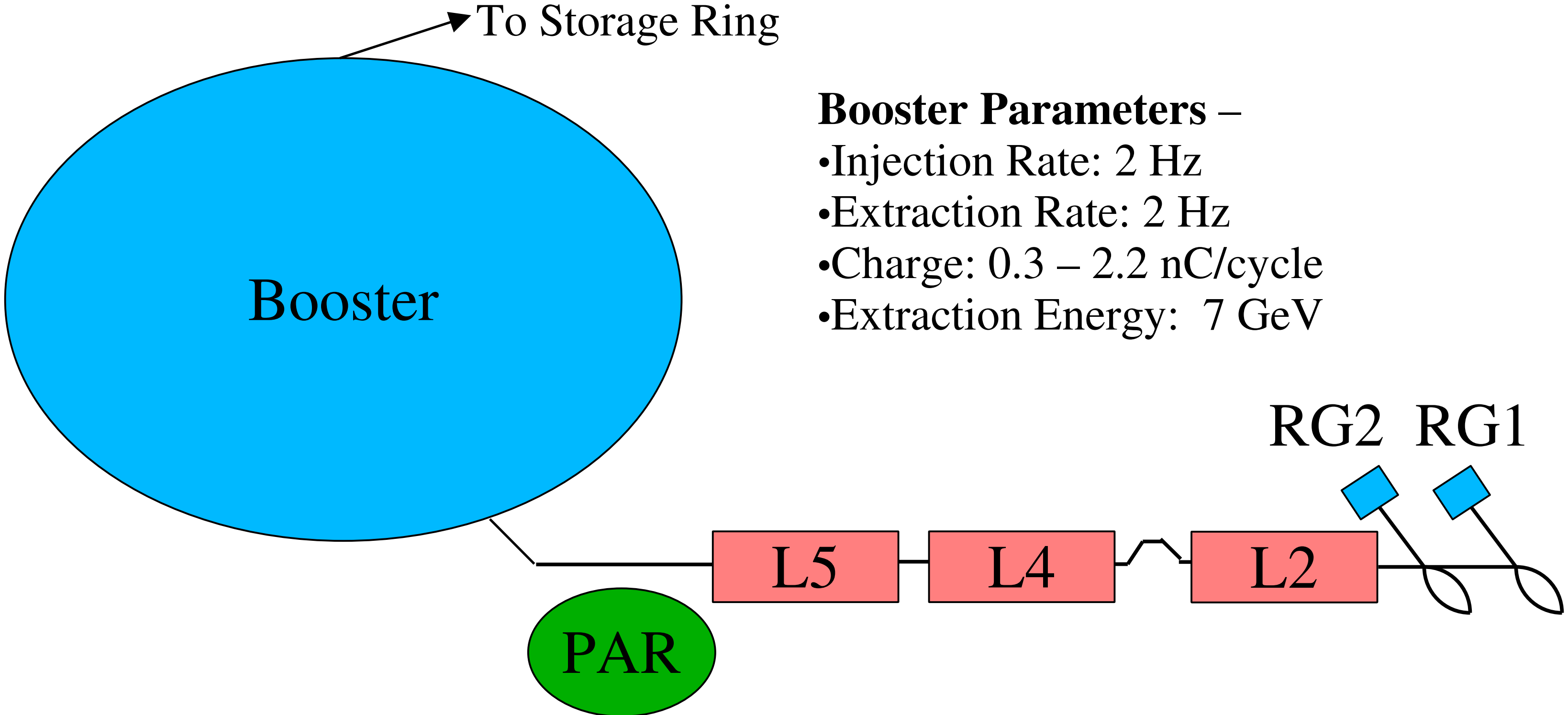
Injector Safety / Operating Envelope Summary

- Safety envelope based on highest allowable average beam power, highest average repetition rate and highest possible operating energy (Safety Assessment Document Ch. 5).

Machine	Safety Envelope	Operating Envelope
Linac (LEUTL), (700 MeV, 60 pps)	(1kW), 24 nC / Pulse	(825 W), 19.7 nC / Pulse
PAR, (500 MeV, 2 Hz)	(20 W), 20 nC / Cycle	(10 W), 10 nC / Cycle
Booster, (7.7 GeV, 2 Hz)	(308 W), 20 nC / Cycle	(154 W), 10 nC / Cycle

- Rep rates are 60 pps for linac/leutl and 2 Hz for par/booster.
- When using PAR and booster there is a factor of 3 margin to support top-up.
- Design booster subharmonic cavity to operating envelope for direct injection.

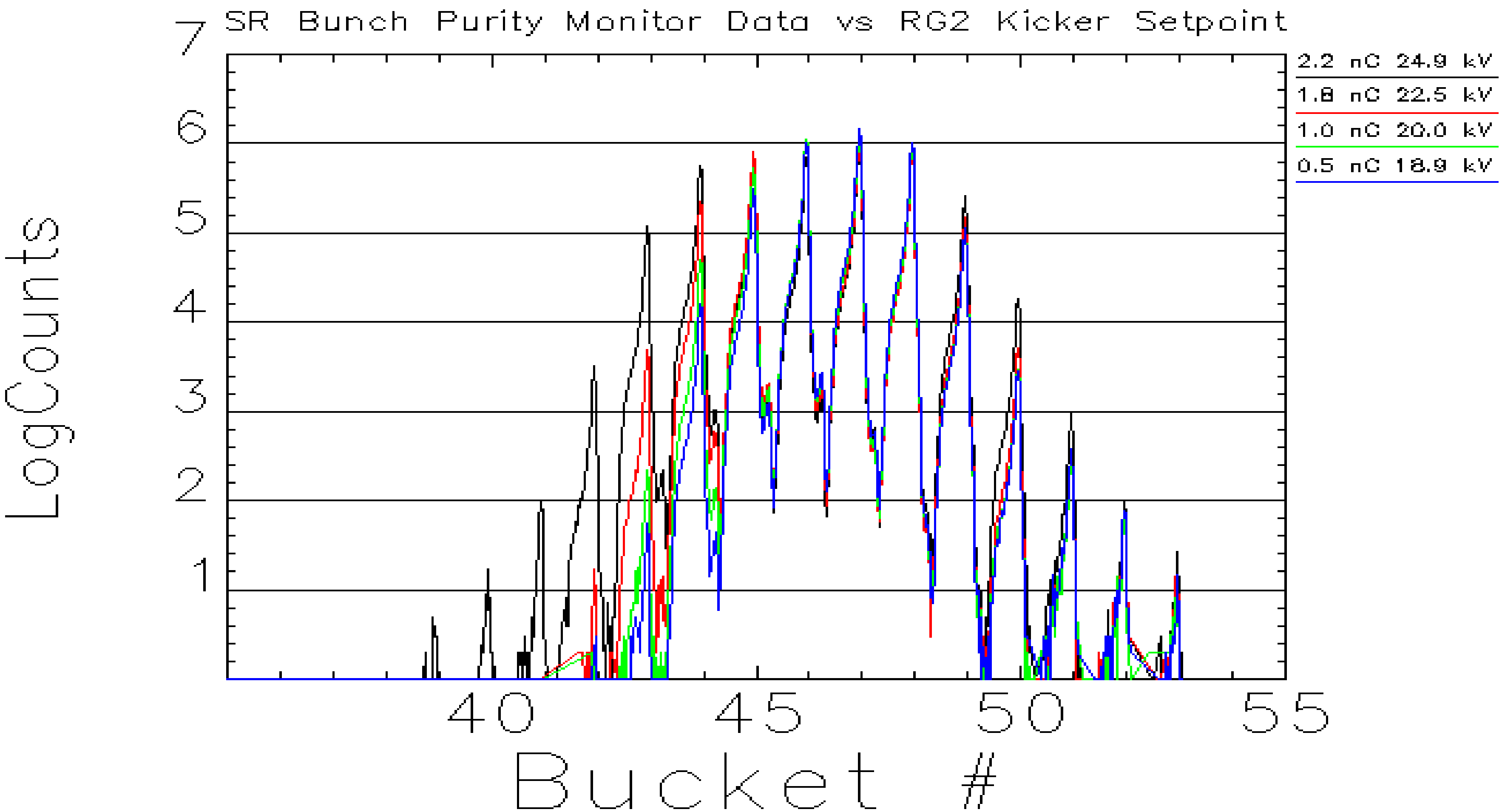
Injector Configuration and Operation for Direct Injection Using rf Gun2.



Booster Parameters –
- Injection Rate: 2 Hz
- Extraction Rate: 2 Hz
- Charge: 0.3 – 2.2 nC/cycle
- Extraction Energy: 7 GeV

LINAC Parameters -
- Injection Rate: 2 Hz
- Extracted Charge: 0.3 – 2.2 nC/cycle
- Extraction Energy: 325- 450 MeV
- RG2 Macropulse Length – 11-16 ns.

Direct Injection – Storage Ring Bucket Pattern



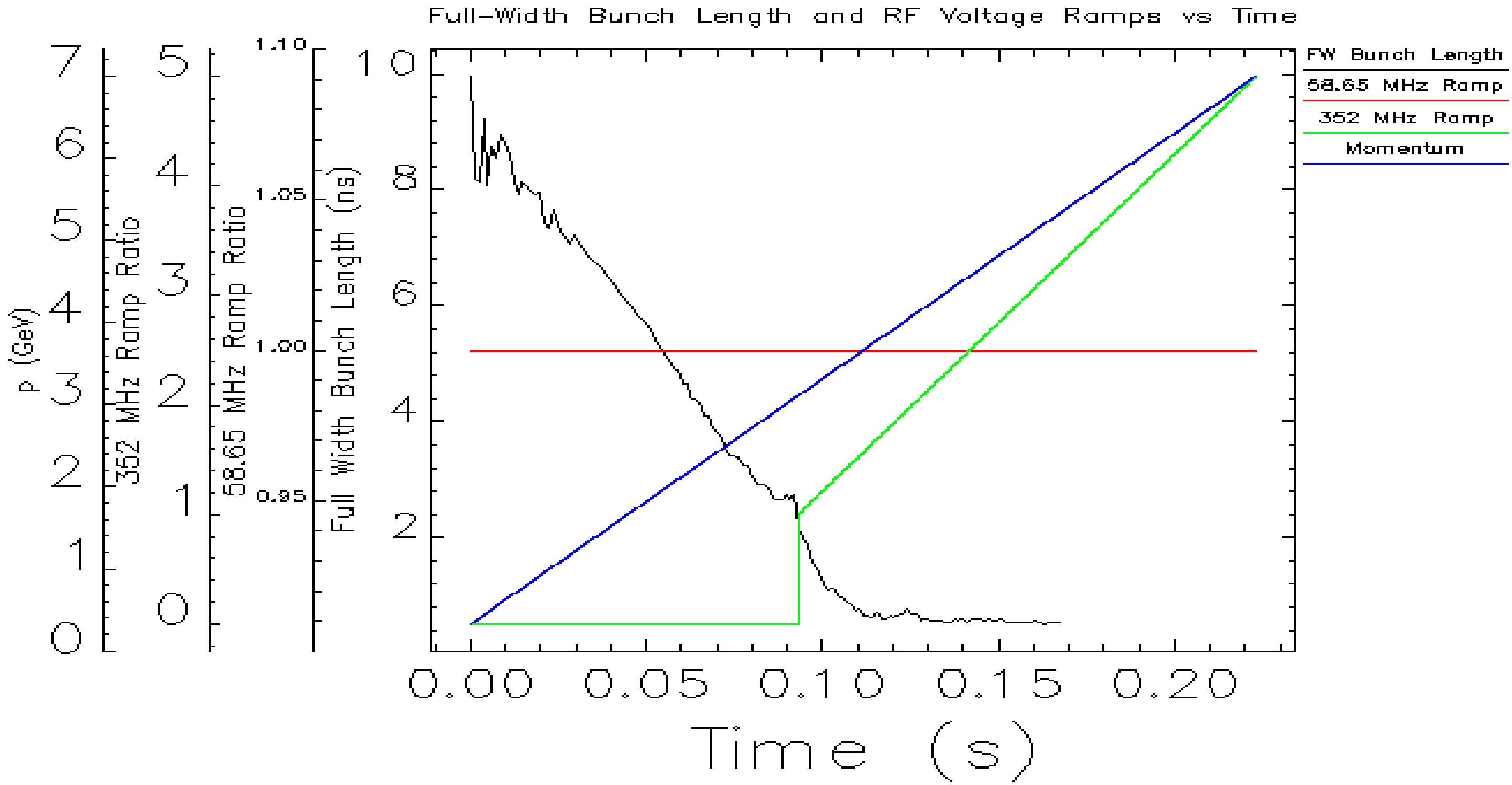
Direct Injection Bucket Pattern Summary

Gun 2 Kicker Setpoint (kV)	Storage Ring Buckets with more than 10 counts	SR Buckets Containing more than 95 % of the Beam
24.9 (2.2 nC/Cycle)	15	6 (16.7 ns)
22.5 (1.8 nC/Cycle)	12	5 (13.9 ns)
20.0 (1.0 nC/Cycle)	11	4 (11.1 ns)
18.9 (0.5 nC/Cycle)	11	4 (11.1 ns)

Booster Subharmonic Cavity ELEGANT Simulations

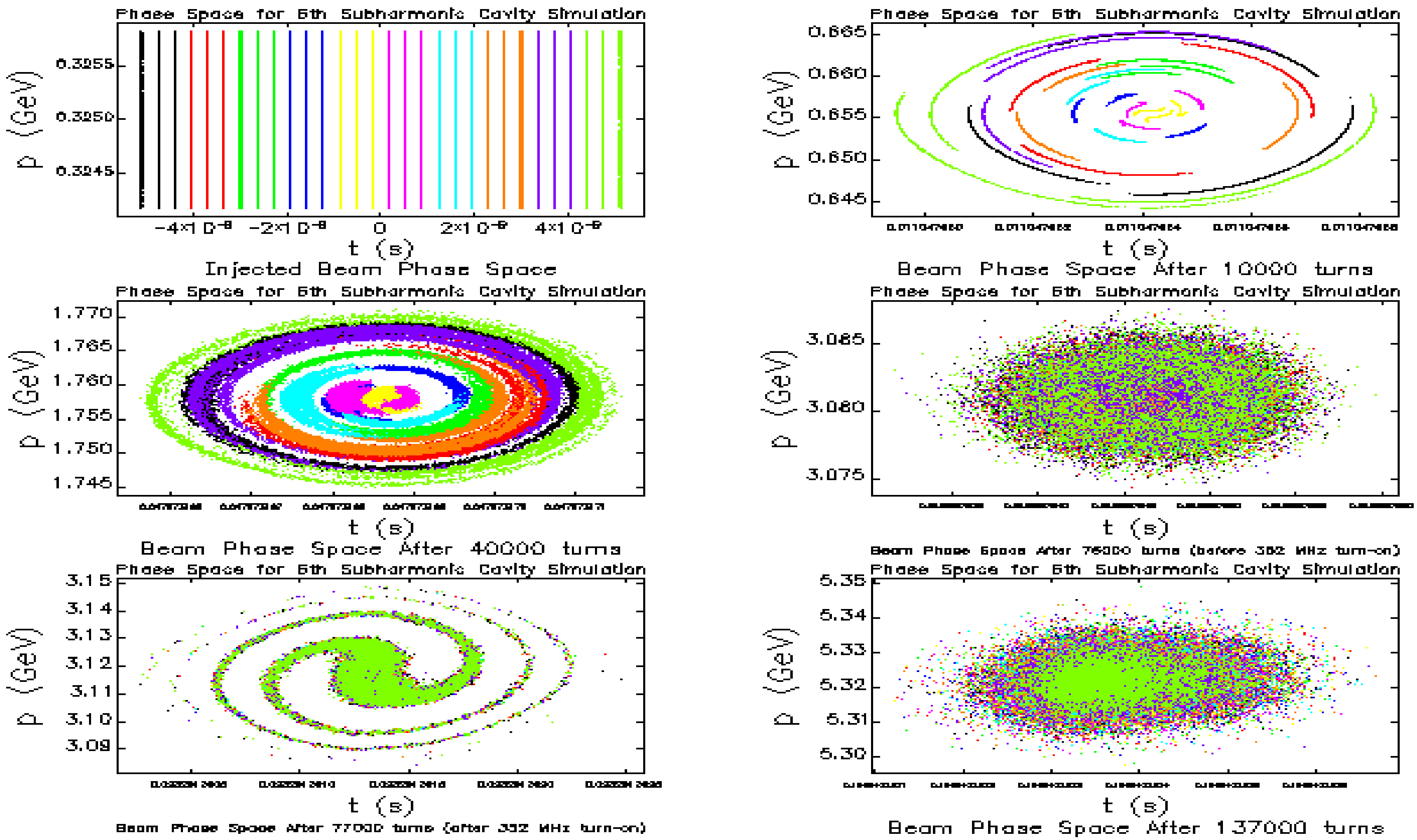
- Use the existing booster momentum ramp rate (325 MeV -> 7 GeV in 223 ms).
- Simulate using a single 352 MHz rf cavity system and a low frequency rf system at a subharmonic of 352 MHz.
- Include beam loading in the simulations.
- Tune 352 MHz system on resonance when the bunch is short enough to be completely captured (~2.5 ns).
- Use 110,000 particles to demonstrate at least 1 part in 100,000 bunch purity (1 part in 1,000,000 desired).
- Include radiation damping and quantum excitation.
- May require bunch cleaning at low energy before 352 MHz system is turned on.

Direct Injection Simulation Using Subharmonic Cavity



FW Minimum Bunch Length = 0.508 ns

Direct Injection Simulation Cont.



Direct Injection Using Subharmonic Booster Cavity Parameter Tradeoffs

Subharmonic Cavity Parameters To Achieve ~2.5 ns bunch length at ~3 GeV
From Elegant Simulation

Frequency (MHz)	Subharmonic Number	Subharmonic Gap Voltage (kV)	Linac Macropulse Length at 0.325 GeV (ns)	Minimum Bunch Length (ns)
29.327	12	650	15.36	2.44
39.103	9	500	12.94	2.57
43.991	8	450	11.44	2.57
58.665	6	400	8.40	2.33

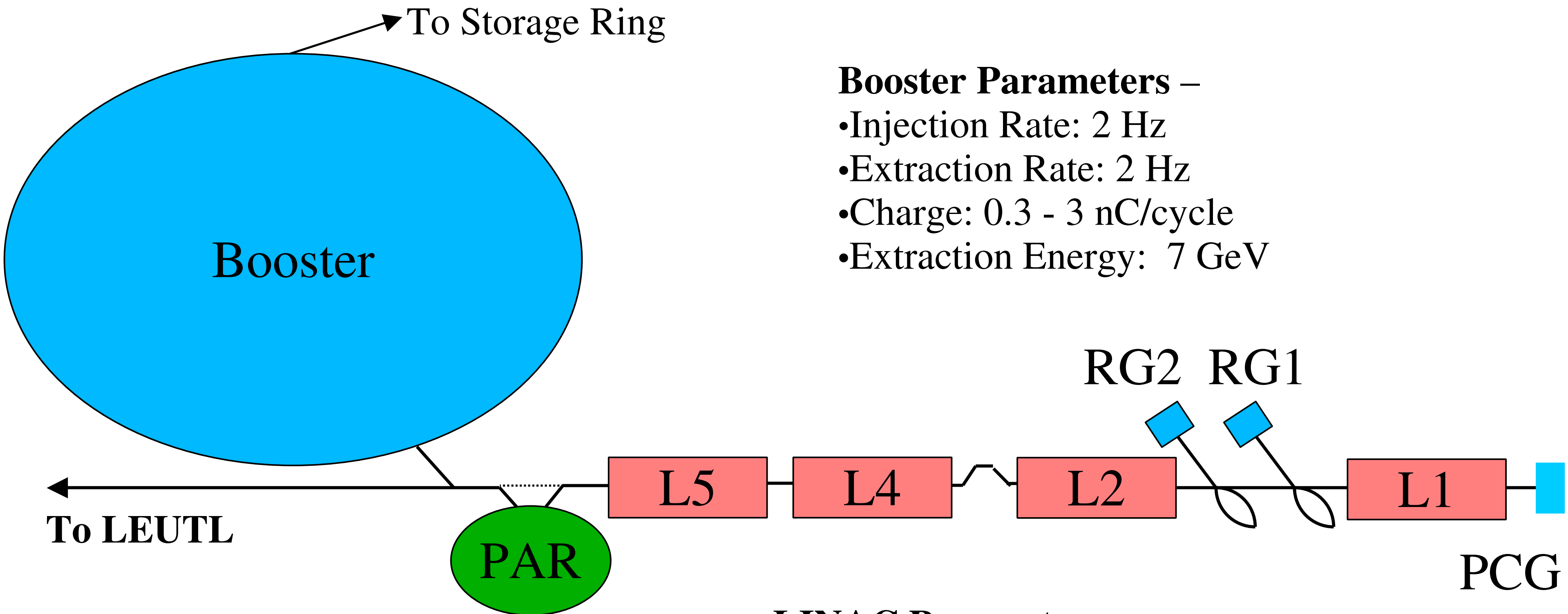
Direct Injection Using rf Guns Driven by a Long Pulse Laser Operations/exp. Issues.

- Idea driven by subharmonic cavity parameter tradeoffs.
- Design to 10 nC / pulse booster operating envelope.
- 5 ns macropulse implies 2 amps off the cathode. What are the limits here?
- Could use 117 MHz subharmonic capture cavity with 5 ns macropulse.
- Bunch cleaning in the booster probably required but easier with subharmonic capture.

Direct Injection Using rf Guns Driven by a Long Pulse Laser Operations/exp. Issues Cont.

- What is the lifetime of cathodes under drive pulse laser conditions?
- What is the drive laser lifetime?
- Emittance measurements.
- Want to use the ITS to demonstrate as many operations issues as possible.
- Eventually test idea using gun 2 after test stand demonstration.
- Repeat storage ring bunch purity measurements.
- Gun 1 needs to be modified to have the same performance as gun 2.
- Gun 1 and PAR in the meantime can still be backup to gun2.

Interleaving Injector Configuration With PC Gun and PAR for top-up

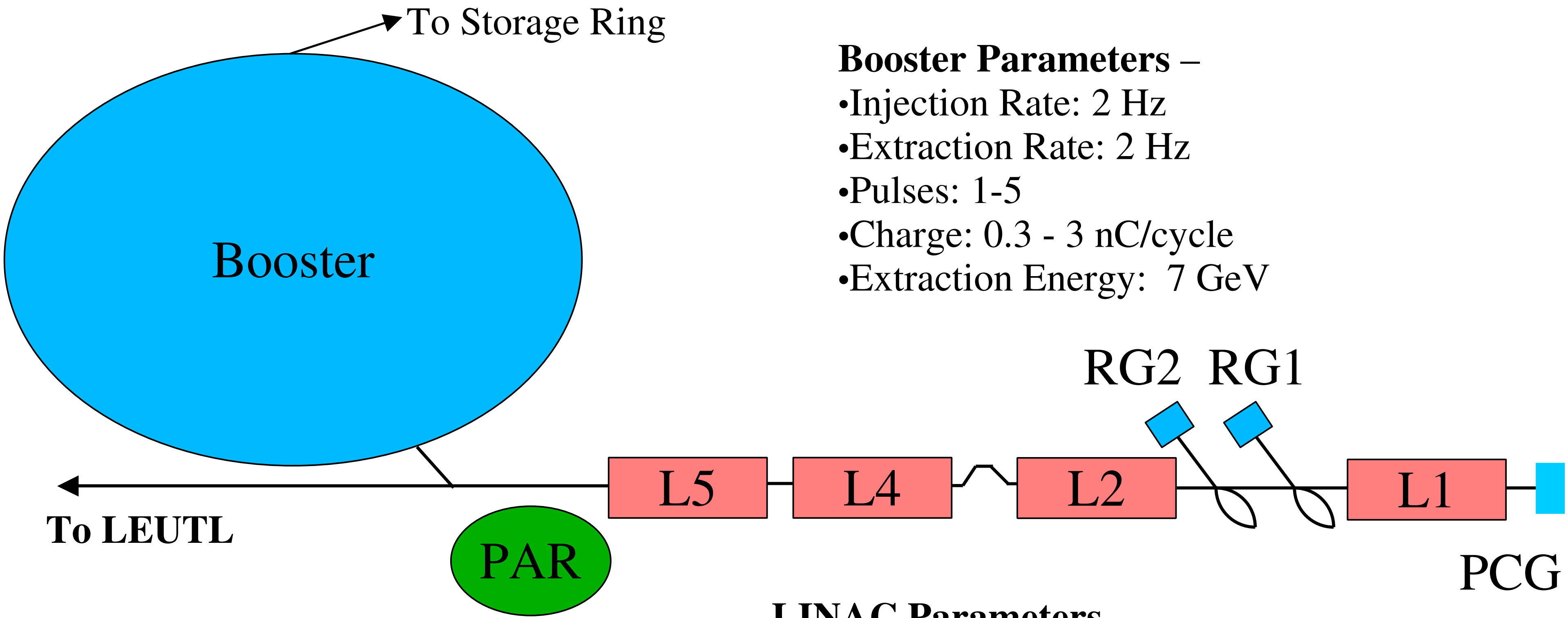


Booster Parameters –
- Injection Rate: 2 Hz
- Extraction Rate: 2 Hz
- Charge: 0.3 - 3 nC/cycle
- Extraction Energy: 7 GeV

PAR Parameters -
- Injection Rate: 6 Hz
- Extraction Rate: 2 Hz
- Injection Pulses: 1-3
- Extracted Charge: 0.3 – 3 nC/cycle
- Injection Energy: 325 – 450 MeV

LINAC Parameters -
- Pulse Rate: 6 Hz
- Injection Pulses: 1-3
- Extracted Charge: 0.3 – 1 nC
- Extraction Energy: 325 - 450 MeV

Interleaving Injector Configuration With Direct Injection Using the PC Gun



Booster Parameters –
- Injection Rate: 2 Hz
- Extraction Rate: 2 Hz
- Pulses: 1-5
- Charge: 0.3 - 3 nC/cycle
- Extraction Energy: 7 GeV

LINAC Parameters -
- Pulse Rate: 6 Hz
- Injection Pulses: 1-3
- Extracted Charge: 0.3 – 3 nC/cycle
- Extraction Energy: 325 - 500 MeV

PC Gun/LEUTL and Top-up Options

- **Interleaving using the PAR.**
  - Use the PAR to accumulate the PC gun beam.
  - Can run PC gun at relatively low charge required for FEL experiments.
  - Can use almost the full linac energy (PAR design energy is 450 MeV).
  - Requires a PAR kicker upgrade to go to the full PAR energy.
  - May need pulsed quads for matching the PC gun beam into PAR.
- **Direct injection into the booster.**
  - No subharmonic cavity required.
  - High charge required (at least 3 nC/cycle every 2 minutes).
  - Can use full energy of the linac.
  - Demonstrated direct booster injection only in studies. Need to resolve timing issue of laser and 352 MHz.

Conclusion

- Top-up represents puts the most severe requirements on the injector in terms of charge/cycle.
- Existing rf guns + PAR meet and exceed top-up requirements and provide the boundary condition for proposed injector modifications.
- Direct injection has been demonstrated using RG2 and can be used to fill the SR in the event the PAR is down.
- Subharmonic capture has been simulated for the booster.
- Can long drive pulse laser be used to shorten the rf gun macropulse?

Conclusion Cont.

- PC gun could in principle be used to support top-up / LEUTL operations.
- Interleaving using the PC gun and PAR is the least severe on PC gun for top-up operations.
- May require pulsed quads to match beam into the PAR.
- Need to run PC gun at least 3 nC / pulse for direct injection top-up.
- Direct injection has been demonstrated using PC gun but timing issue needs to be resolved.